NEED FOR ACCURATE TRAFFIC DATA IN PAVEMENT MANAGEMENT: JOHN F. KENNEDY INTERNATIONAL AIRPORT CASE STUDY

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PRESENTED FOR THE
2004 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Atlantic City, New Jersey, USA

April 2004

INTRODUCTION

Pavements are a key element of the airport infrastructure. They are required to be in a high state of repair to ensure safe delivery of people and goods and to minimize the structural impact on aircraft. Maintenance and repair (M&R) of pavements carry high capital and user costs. M&R decision-making is critical and has widely been based on extensive knowledge and experience.

Pavement management brings more science into the decision-making process, supplementing and enhancing the knowledge of the decision-maker. It includes condition and inventory data collection; storage and maintenance of this data; and analysis of the data to evaluate M&R strategies for decision-making. The accuracy of all data is key to a quality analysis.

Data utilized in pavement management analysis includes structural layer information, pavement geometry, traffic mix and volumes, surface distress, construction and maintenance histories, maintenance policies and prioritization, and costs. The focus of many pavement management systems (PMS) tends to be on the surface distress condition, without assessing structural impacts beyond those identified through surface conditions and associated deterioration curves.

Aircraft induced loadings is a significant factor in pavement performance and an important consideration in the pavement management process. Some PMS analytical modules can use traffic and structural data to calculate the actual impact on the pavement in terms of remaining life, in accordance with FAA airport pavement design procedures. This in turn is used in the prediction of future condition and design requirements. Despite its importance in the performance of the network pavements, traffic data is commonly not quantified accurately in PMS, generally not verified in the field, and many years can pass between updates to the traffic data.

The Port Authority of New York and New Jersey has undertaken a number of studies over the past several decades aimed at development of a comprehensive pavement management system (Rada, Rabinow and Zee [1]). Subsequently, an Airport Pavement Management System (IAPMS) was developed and implemented at John F. Kennedy International Airport (JFK) in 1987. An update to the traffic data has recently been implemented.

This paper explores the impact of aircraft traffic loadings on the pavement management process through a case study JFK. The first part of the paper provides an overview of the methods used for the initial PMS data inputs of both traffic and structural data in the late 1980’s. The recent traffic data update is reviewed next and the significance of accurate traffic data in terms of sensitivity of the structural remaining life to the change in both aircraft mix and volume is discussed. While structural remaining life is also sensitive to variations in aircraft weight as is well documented in available literature, the sensitivity is not documented in this paper. Some of the findings from the traffic update include: changes in volume for 90% of PMS sections in excess of $\pm$ 10%; a significant decrease in the number of Boeing 747, 757 and 767 aircraft; and a significant increase in dual gear aircraft. More importantly, the updated mix represents a less structurally damaging mix, as shown in the paper through various sensitivity analyses.

PAVEMENT MANAGEMENT at JFK

Pavement management in the early days was done by airport engineers. This generally included a visual inspection with the resulting maintenance and rehabilitation activities recommended for that same year. Forecasting and multiyear planning was generally not considered. A product of this system was the experience and first hand knowledge of the engineers of their pavements. The data was not kept in an inventory database, but rather was maintained within the knowledge-base of the experienced personnel.

Over time aircraft traffic increased, jumbo jets entered the mix, airport congestion increased, and experienced engineers began to retire taking their knowledge with them. Therefore, a better pavement management system was needed to ensure timely and budget conscious decisions were made for maintenance and rehabilitation activities (Rada, Rabinow and Zee [1]).

At JFK, this meant evolving to an inventory system that did not depend on the memories of individuals, but rather recorded the condition at a point in time, and had the capabilities to forecast conditions such that multi-year planning could be performed.

In setting up the system, historical data was collected to include layer thickness and material properties. This proved difficult and time consuming, and was done using a range of resources from construction records to the assistance of vintage engineers (Rada, Rabinow and Zee [1]). Additionally, the Port Authority provided traffic data in the form of arrival and departure volumes by aircraft type. Routing assumptions were made and volume and mix data were assigned at the IAPMS section level with one mix for the whole airport, regardless of use (PCS [2]).

The focus of many pavement management systems tends to be on the surface distress condition, without assessing structural impacts beyond those identified through surface conditions and associated deterioration curves. Some analytical modules, however, can use traffic and structural data to calculate the actual impact on the pavement in terms of remaining life, in general accordance with FAA airport pavement design procedures. This in turn is used in the prediction of future condition and design requirements.

The Port Authority recognized the importance of not only surface distress data but also structural data for forecasting condition. Therefore, in addition to collecting surface distress data, they also collected non-destructive deflection (NDT) data. Using material properties that included CBR, the Port Authority pavement management system included both pavement condition index (PCI) and remaining life (RL) predictions.

The overall product was a system that enabled the Port Authority engineers to make rational predictions of future pavement condition and performance, essential for sound management and accurate budget forecasting. (Rada, Rabinow and Zee [1]). In September 1992, *Public Works Magazine* reported that the implementation of the Port Authority pavement management system at their major airports resulted in an estimated annual savings of $200 thousand in engineering and line department costs.

Since implementation, the Port Authority has been diligent in maintaining and updating their IAPMS. Construction records continue to be collected, reviewed, and recorded in IAPMS capturing changes in layer thickness and properties. Surface distress data is collected and updated in the system and annual forecasting is done to continually update maintenance and budget plans.

PMS TRAFFIC DATA

The traffic mixes and volume have been changing and evolving since the implementation of the system, therefore, the Port Authority recognized that a reevaluation of the traffic data, one of the key elements within IAPMS, was needed. The remainder of this section addresses the traffic data needs for IAPMS.

The damage from any aircraft traversing a pavement is a function of the aircraft's weight; the gear configuration imparting the aircraft weight onto the pavement; and the composition of the pavement structure itself.

Pavement structures are designed to withstand a design number of aircraft operations. These operations are typically modeled as a single aircraft type even when the true traffic consists of many different aircraft. The Boeing 747-200B is used as the IAPMS design aircraft for JFK. For any aircraft type, the damage of an arriving aircraft is computed to be less than that of a departing one, on the basis of fuel-related weight differences. For PMS at JFK, aircraft are assumed to depart at their Maximum Gross Take-Off Weight (MGTOW) and arrive at 70% of their MGTOW. FAA design procedures rely on the number of departure operations of an aircraft; essentially the worst-case condition in terms of MGTOW. The IAPMS, however, can distinguish between arrival and departure operations at the section level. Therefore, since PMS can be an inventory tool as well as provide analysis capabilities, it was implemented with actual traffic data to include both arrival and departure volumes.

The desired number of *operations* is used for design of new pavement. For pavement management purposes, the actual pavement structure/subgrade support combination of in-place pavements is used to determine the remaining *operations* to pavement failure. The remaining *operations* the pavement can withstand before failure can be viewed as **Remaining Life (RL)** where;

$$RL_{(years)} = 1 - \frac{N_p}{N_f}$$

Where: N_f = *Number of design operations to failure*
N_p = *Number of operations to date*

IAPMS uses this methodology to determine the remaining life of pavement based on the allowable operations of a standard aircraft, over the pavement structure and subgrade support for each pavement section. The IAPMS module uses aircraft characteristics (MGTOW, landing gear properties, etc.) to calculate engineering properties for the aircraft and calculates an equivalent number of operations of a design standard aircraft (Boeing 747-200B for JFK). This method of calculating equivalent standard aircraft operations is used to convert the complex mixed traffic into a form suitable for comparison to FAA design requirements for the pavement structure. A detailed description of the IAPMS computational methods are contained in “Aircraft Traffic Mix Analysis: Damage Factors and Coefficients” (Rada and Witczak [3]).

Therefore, the traffic information needed for the traffic update at JFK included the number and type of aircraft traversing the airfield pavements. IAPMS stores this data as two traffic statistics, aircraft mix and volume, for each PMS section to support remaining life and other design analyses.

Aircraft mix is a frequency table or matrix of the aircraft type traversing the pavement section. The distribution is expressed on a percentage basis, and separate aircraft mixes may be stored for arrivals and for departures. A simplified, example aircraft mix is shown below.

Table 1.
Arrival Aircraft Mix.

Aircraft Type	**Operations (%)**
B-747-400	20
B-767-300	40
MD-11	20
A-320-200-1	20

Volume is the total number of aircraft movements over the pavement section on an annual basis. Separate volume statistics are provided for arrivals and for departures to distinguish their take-off and landing weights.

The network of runway and taxiway pavements at JFK is segmented into sections varying in length from 55 feet to 2600 feet. This segmentation is generally based on the section having homogenous pavement characteristics throughout its length. The pavement network at JFK is divided into 374 PMS sections. Inventory information and condition data are stored, and analyses are performed at the section level. The recent traffic update included update of the aircraft mix and volume data for all 374 PMS sections utilized at JFK. Improving the reliability of the aircraft mix and volume statistics increases the reliability of remaining life estimates used in pavement management, and improves the design efficiency (over or under design) of maintenance and rehabilitation activities.

PMS TRAFFIC UPDATE

The Port Authority collects daily flight statistics directly from the flight strips. The data is compiled into a database and can provide arrival and departure information such as runway use, flight identification numbers, FAA aircraft classifications, service type, and date and time for each aircraft operation. All data is at the runway level. No traffic count data at intersections was available. Therefore, the challenge of this project was to route the aircraft traffic across the pavement network between the arrival/departure runway and myriad of terminals, hangers and cargo buildings.

For the routing analysis, however, additional data than that provided on the flight strips was required. In the absence of budget for traffic counting efforts, an approach similar to that used in the initial pavement management implementation was taken; which was to talk to the people with knowledge. This included FAA tower and JFK Operations personnel. These people are on-site daily and direct traffic throughout the network.

We developed a mathematical model of the runway and taxiway system using origin and destination information with a constrained path routing assignment approach (Handbooks in Operations Research [4]). This involved developing all traffic flow options physically possible, for each arriving and departing runway. An example of one flow diagram is provided below for traffic arriving on runway 4R and proceeding to Terminal 1.

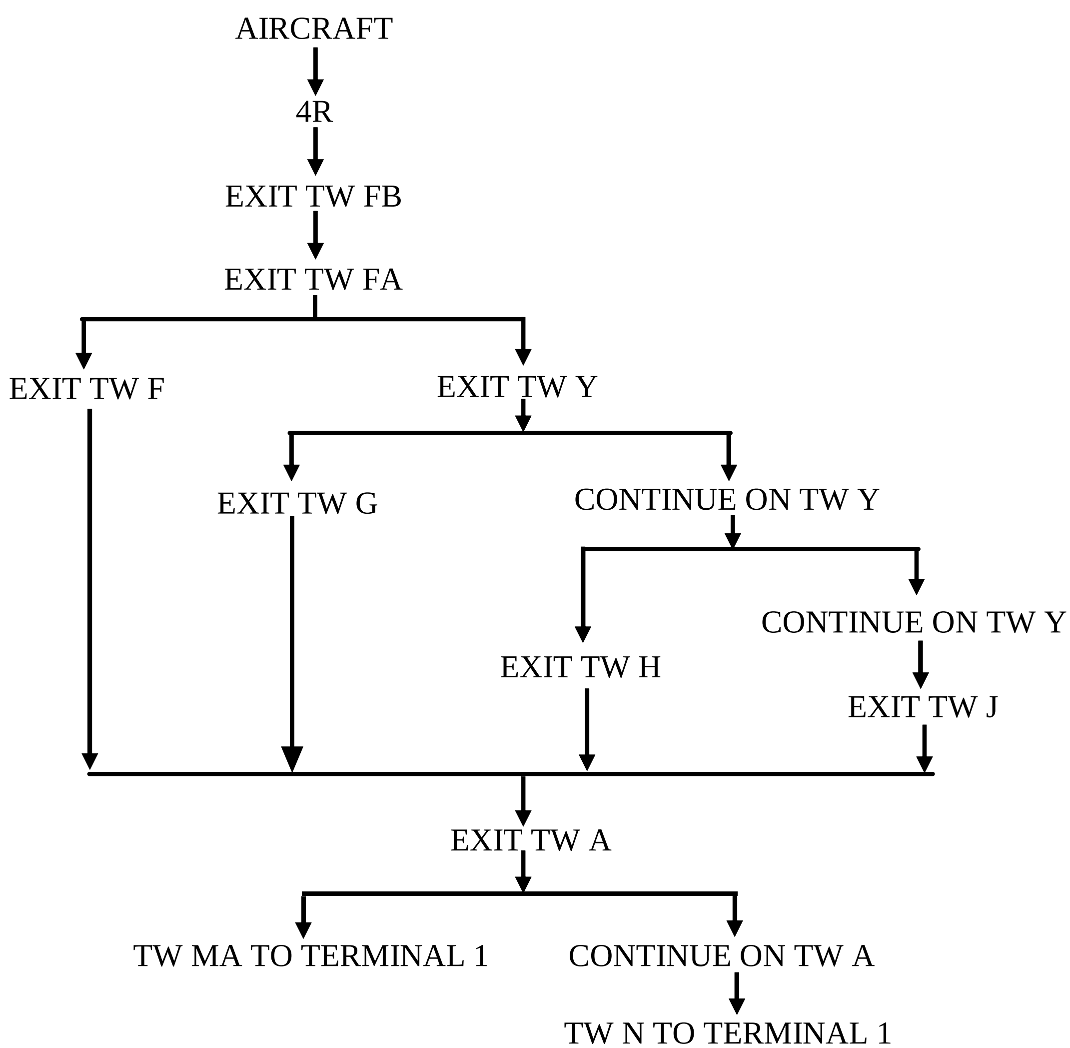


Figure 1. Flow Diagram Runway 4R to Terminal 1.

From this flow diagram, we identified the types of data needed to finalize the models. This included the following items:

a. Tenant assignment by terminal / cargo
b. Gate assignment by tenant
c. Aircraft type for each tenant
d. Exit taxiways used by specific aircraft types
e. Air traffic ground control general guidelines
f. Operating practices and probabilities for cross wind, bad weather, peak hours etc.
g. Directional taxiways
h. Runway landing and takeoff points

Personnel from the FAA Tower and JFK Operations were able to satisfy much of the data needs identified above. This proved invaluable to the success of the project.

Annual volume data was compiled from the Port Authority database. The 12-month period selected for determination of annual traffic was September 1, 2000 to August 31, 2001, and the total traffic volume was 337,760.

The first application of the traffic volume datasets to the traffic flow model created results that were difficult to analyze and interpret because of the large variety of aircraft designators. The large number of aircraft designators, often representing only subtle model differences, means the occurrence frequency of many aircraft types is very low. To improve comprehension of the results, we grouped similar aircraft. Since this is to support pavement management activities, we grouped the aircraft on the basis of their weight and gear characteristics, preserving the concept of *operations.*

Over 350 different aircraft designators were simplified and condensed into a manageable set of aircraft groupings as contained in the table below. Each group has a **Representative Aircraft** that is the most commonly occurring aircraft type at **JFK** within each grouping.

Table 2.
Aircraft Groupings.

Representative Aircraft	**Gear Type**	**MGTOW (lbs)**
B-747-400	Double Dual Tandem	> 750,000
B-777-200	Triple Tandem	> 660,000
MD-11	Dual Tandem	≥ 500,000
B-767-300	Dual Tandem	350,001 to 499,999
B-757-200	Dual Tandem	< 350,000
A-320-200	Dual	≥ 60,000
SF-340	Dual or Single	< 60,000

Traffic Update to Pavement Management System, MACTEC professional report.

The filtered data partitioned for each runway configuration and each aircraft group was then applied to the traffic flow models. These modeling runs produced **aircraft mix** results and aircraft **volume** counts for each of the 374 PMS sections. Separate statistics were modeled for arrivals and for departures.

Although results were produced for each individual IAPMS section, many IAPMS sections have similar or identical results. For instance, two adjacent taxiway sections without an intersection present must carry the same traffic. This results in there actually being 170 distinct mixes for arrivals and 125 for departures.

The computational power of IAPMS to handle information at this level of detail has to be balanced by the effort required to comprehend, verify, update and maintain the data. We evaluated the mixes to determine the significance of their differences from a pavement management perspective. Further analysis was done based upon the relative damage effect of each mix, to combine similar mixes. This reduced the number of unique aircraft mixes to 18 for arrivals and 19 for departures, some of which are provided in the table below.

Table 3.
Departure Traffic Mixes.

Representative Aircraft	Gear Type	Mix #1	Mix #2	Mix #3	Mix #4
B747-400	Double Dual Tandem	10.7	99.4	0.5	25.8
B777-200	Triple Tandem	1.8	0	0	0
MD-11	Dual Tandem	3.8	0.3	0	0.2
B-767-300	Dual Tandem	26.7	0	0	14.6
B-757-200	Dual Tandem	11.7	0	0	47.7
A-320-200	Dual	22.1	0	99.5	11.6
SF-340	Dual or Single	23.2	0.3	0	0.1

Table 4.
Arrival Traffic Mixes.

Representative Aircraft	Gear Type	Mix #1	Mix #2	Mix #3	Mix #4
B747-400	Double Dual Tandem	18	45.8	33.5	27.6
B777-200	Triple Tandem	2.9	2	0.6	0
MD-11	Dual Tandem	0	0.5	0.3	18.5
B-767-300	Dual Tandem	48.8	0.5	15.4	15.1
B-757-200	Dual Tandem	5.5	29.7	42.2	32.5
A-320-200	Dual	7.8	21.3	7.9	6.3
SF-340	Dual or Single	16.9	0.2	0.1	0

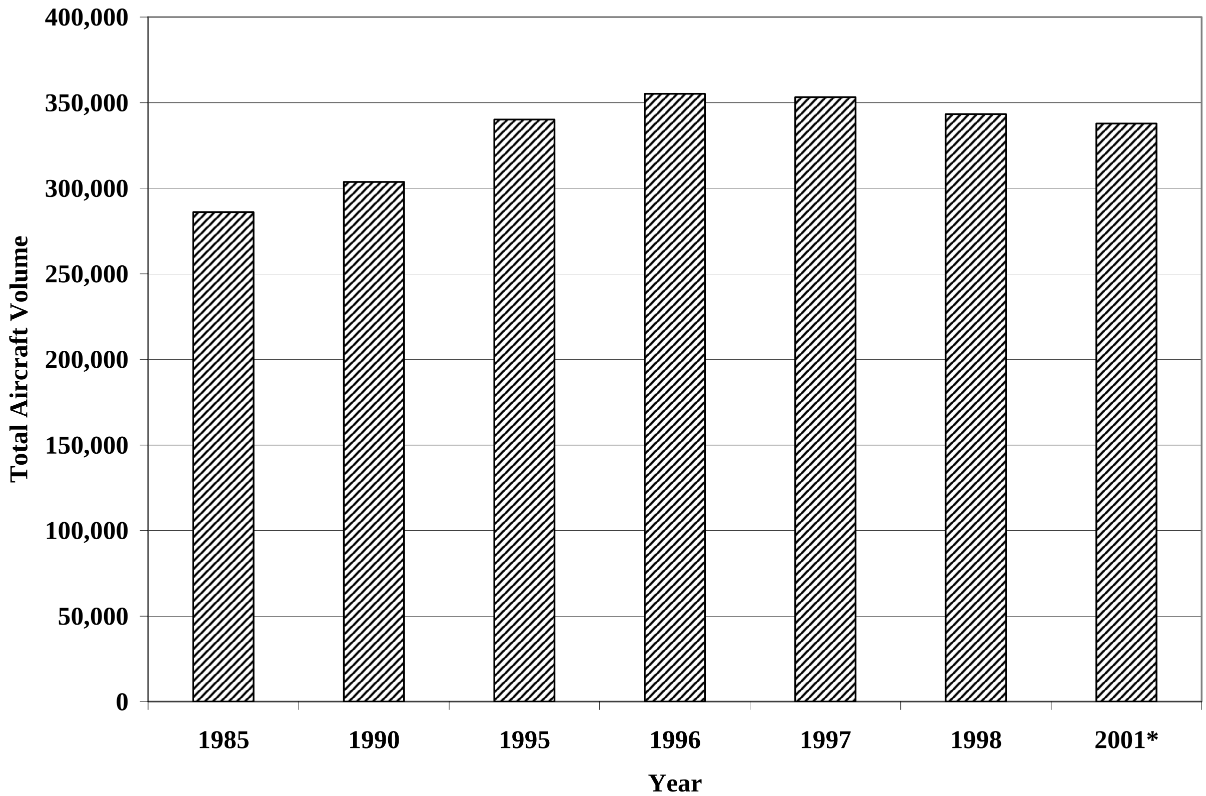
IMPACT OF PMS TRAFFIC DATA UPDATE

The traffic update produced changes in both mix and volume at the IAPMS section level. The changes, and impact of these changes are provided in the sections below.

Volume Update

The traffic statistics resulting from the modeling conducted in the project (**2001**) were compared to the data in IAPMS (**1987**).

The total volume of arrival and departure flights was reviewed with historical volume data as provided by the Port Authority (Port Authority [5]). Volume peaked in 1996, and has been decreasing since that time. The overall increase in volume, however, since the IAPMS implementation, is approximately 38,000 or over 12%.



**Data from September 2000 to August 2001.*

Figure 2. Total Aircraft Volume.

A comparison of the 2001 and 1987 volume data at the section level for each of the 374 PMS section shows the following:

- 90 % of sections experienced a volume change in excess of 10% where:
  - 30% of sections increased in volume
  - 60% of sections decreased in volume

This change in volume at the section level is a result of the improvements in traffic routing assignments modeled within this project.

A remaining life analysis was performed, using the JFK typical taxiway pavement structure and a traffic mix of one aircraft; the standard design aircraft. The following figure shows the results of the analysis:

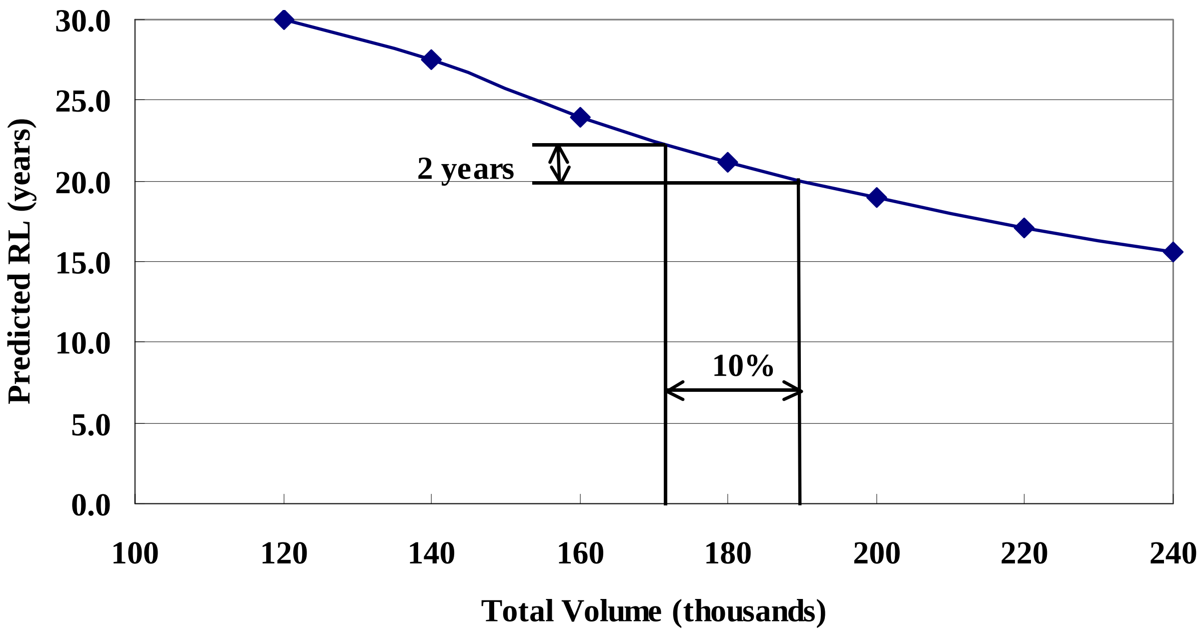


Figure 3. Effect of Change in Volume on Predicted Remaining Life.

Based on the routing models, for a total traffic volume of 337,760 the maximum taxiway section volume is approximately 90,000 arrivals and 90,000 departures, for a total section volume of 180,000. With a 10 % change in volume the remaining life prediction can change by up to 2 years.

Mix Update

Previously one aircraft mix was applied for arrival and one for departure volumes, for all sections of the airfield. These two mixes were based on all aircraft arriving and departing the airport and were the same, since the aircraft arriving would be the same as the aircraft departing. With the traffic update, thirty-seven new aircraft mixes have been produced to reflect the differences in aircraft travel throughout the airfield. For comparison purposes at the airport level, we developed a new overall aircraft mix for 2001 that reflects all aircraft arriving and departing JFK during September 1, 2000 to August 31, 2001, to compare with the old mix below developed in 1987.

Table 5.
Comparison of Aircraft Mixes.

Representative Aircraft	**Gear Type**	**1987 Mix (%)**	**2001 Mix (%)**	**% Difference**
B-747-400	Double Dual Tandem	26.3	10.7	-15.6
B-777-200	Triple Tandem	0.9	1.8	+0.9
MD-11	Dual Tandem	2.5	3.8	+1.3
B-767-300	Dual Tandem	34.6	26.7	-7.9
B-757-200	Dual Tandem	29.2	11.7	-17.5
A-320-200	Dual	6.5	22.1	+15.6
SF-340	Dual or Single	0	23.2	+23.2

Traffic Update to Pavement Management System, MACTEC professional report.

As presented in this table, the overall JFK aircraft mix shows a significant decrease in the volume of Boeing 747, 757 and 767 aircraft, and significant increase in dual gear aircraft such as the Airbus 320. The increase in the single gear aircraft (SF-340) is not significant, as this group of aircraft was not previously considered in IAPMS.

A remaining life analysis was performed, using the JFK typical taxiway pavement structure and the 1987 and the 2001 mix. The results are provided in the following figure:

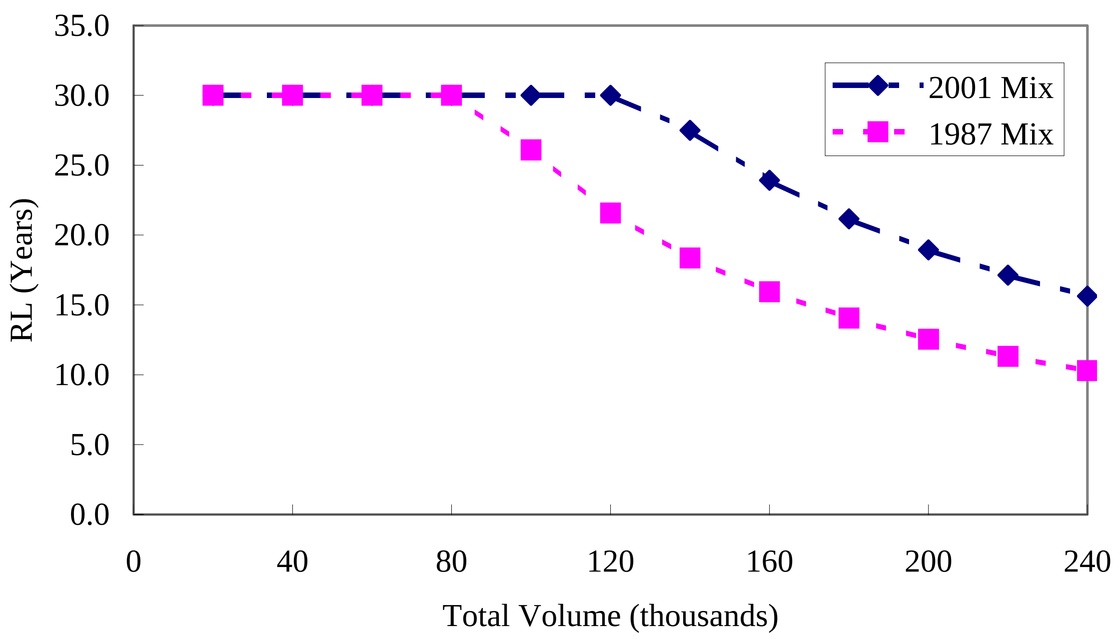


Figure 4. Effect of Change in Aircraft Mix on Predicted Remaining Life.

As indicated in the figure, the 2001 mix represents a less structurally damaging mix than the 1987 mix. At a total volume of 180,000, the RL has increased by 7 years with the 2001 mix.

The traffic update allowed for the accommodation of the differences in aircraft travel throughout the airfield. Within the thirty-seven new mixes, there are distinct differences. To appreciate the impact of the different mixes, we chose three distinct departure mixes, to compare to the 2001 mix. These mixes represent a cargo mix, comprised mainly of Boeing 747's (Cargo), a dual gear mix representative of a specific tenant (A320) and a taxiway mix with high Boeing 757 and 747 components (757 Mix). The following table and subsequent graph provide details of each mix.

Table 6.
2001 Mix and Distinct Departure Mixes.

Representative Aircraft	Gear Type	2001 Mix	Cargo Mix	A320 Mix	757 Mix
B747-400	Double Dual Tandem	10.7	99.4	0.5	25.8
B777-200	Triple Tandem	1.8	0	0	0
MD-11	Dual Tandem	3.8	0.3	0	0.2
B-767-300	Dual Tandem	26.7	0	0	14.6
B-757-200	Dual Tandem	11.7	0	0	47.7
A-320-200	Dual	22.1	0	99.5	11.6
SF-340	Dual or Single	23.2	0.3	0	0.1

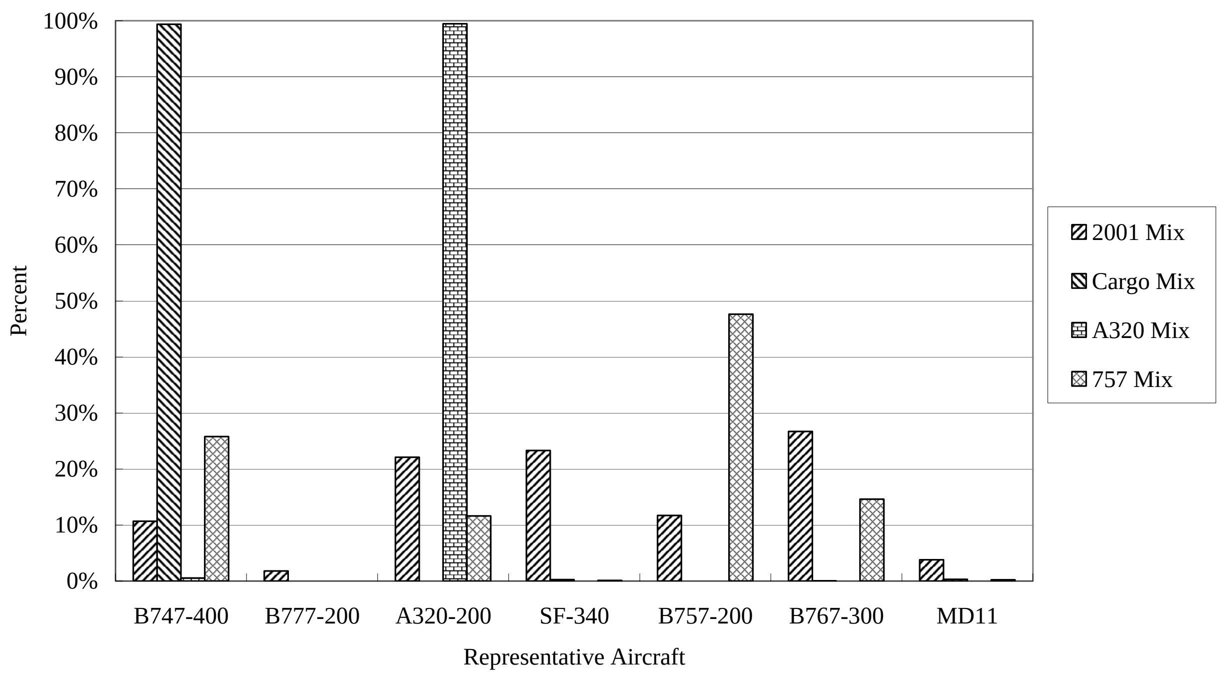


Figure 5. Comparison between 2001 Mix and Distinct Departure Mixes.

A remaining life analysis was performed, using the JFK typical taxiway pavement structure and each of the four mixes. The results are provided in the following figure:

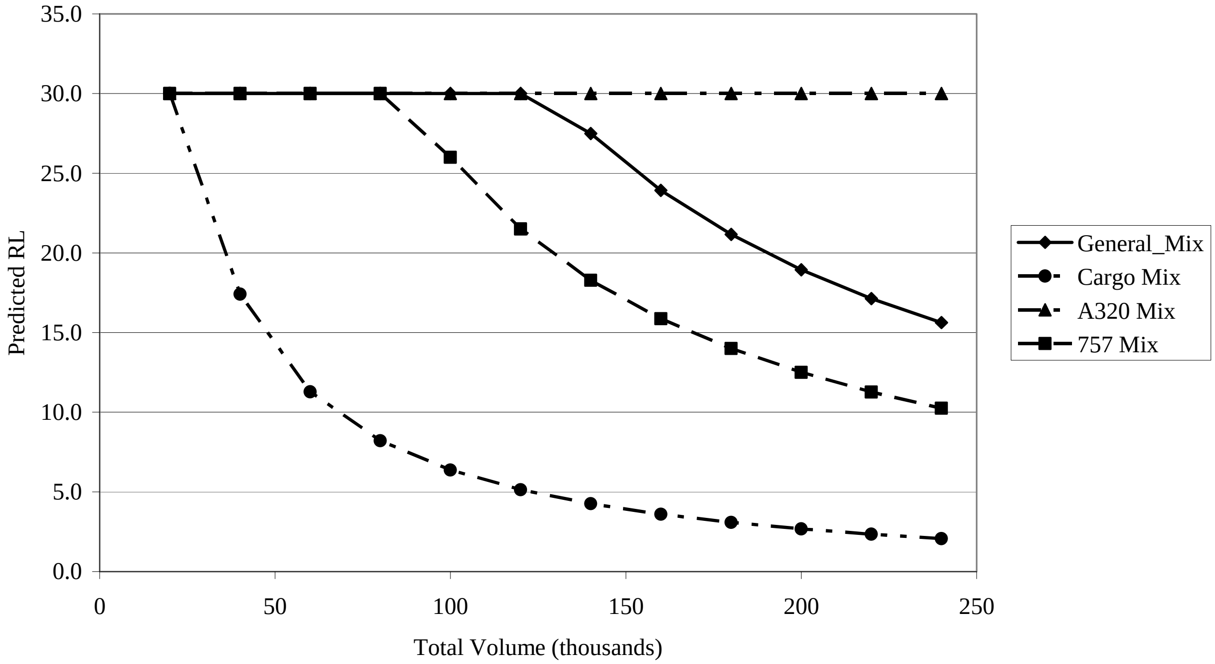


Figure 6. Effects of Distinct Departure Mixes on Predicted Remaining Life.

As indicated in the figure, each mix is significantly different from the general airport mix. The A320 mix is less structurally damaging, while the Cargo mix can decrease remaining life by up to 20 years at a total volume of 180,000.

CONCLUSIONS

Aircraft induced loadings is a significant factor in pavement performance and an important consideration in the pavement management process. Some pavement management analytical modules can use traffic and structural data to calculate the actual impact on the pavement in terms of remaining life, in accordance with FAA airport pavement design procedures. This, in turn, is used in the prediction of future condition and design requirements.

Pavement remaining life can be highly sensitive to changes in either aircraft mix or volume. A comparison of aircraft mix and volume between the 2001 and 1987 data shows significant changes in both.

Aircraft volume at JFK has increased by over 12% since 1987. The traffic update indicated a volume change in excess of 10% on 90% of IAPMS sections. A 10% change in volume can produce a corresponding 2-year change in remaining life.

The overall aircraft mix arriving and departing JFK has changed significantly. Overall, there has been a decrease in Boeing 747, 757 and 767 aircraft, and significant increase in dual gear aircraft such as the Airbus 320. Intuitively these changes seem to reflect changes in fleet composition and aircraft use within the industry. At the airport level, this mix is less damaging structurally and can result in an increase in remaining life of up to seven years.

The use of several arrival and departure aircraft mixes over a single mix will produce even more accurate predictions at the section level. As observed at JFK remaining life can vary up to 20 years, depending on the mix applied to a section.

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